October 16, 1978

R. Dixon/dmt

XVI. 1000 GEV SWITCHYARD UPGRADE

I. Introduction

Over the next 2 years the switchyard will be upgraded to deliver 1000 GeV proton beams to all three Experimental Areas. This report will discuss the schedule and the details for initially attaining this objective. Extraction from the Tevatron will be only briefly mentioned as a starting point for the switchyard discussion because many of the details are undetermined at this time. Also, to be discussed are the additional beam splitting stations being planned for the neutrino and meson beam lines.

Figure 1 gives the overall layout of the switchyard and should be used for the locations of the various enclosures and manholes in the following discussion. The major change necessary for achieving 1000 GeV in the switchyard is the replacement of the conventional EPB dipoles, making up the major horizontal bends in the proton and meson beam lines with superconducting Energy Doubler/Saver magnets. Vertical bending magnets and all quadrupoles will remain conventional in the initial upgrade. Under this plan the neutrino beam line will contain no superconducting devices.

The most significant modification to the neutrino beam will be the addition of a separate muon beam. This will be done by splitting the neutrino beam downstream of the present meson split resulting in a new beam line that will be targeted independently to the east of the present neutrino target area. The new muon beam line will require one set of superconducting dipoles.

The other split to be added in the switchyard will occur in the meson beam line. The first step will be a two-way split initiated in the F1 manhole by one electrostatic septum. This split will only be functional up to 450 GeV, howevever, future plans call for an eventual upgrading to a three-way split that will be operable at 1000 GeV.

II. Extraction

The details of extraction from the Tevatron are currently being worked on by Helen Edwards and Mike Harrison and will not be discussed in detail here. A significant change being considered would move the extraction septa to either D0 or F0 to alleviate the beam loss problem in the Transfer Hall. Also, in the present thinking the extraction Lambertsons and the extraction channel will be located directly beneath their main ring counterparts. Instead of bending the proton beam down at the Lambertsons and away from the accelerator in the extraction channel, the extracted Tevatron beam will be bent up at the Lambertsons (Fig. 2). In order to bring the beam to the present switchyard elevation in the center of the Transfer Hall extension a 5 mr bend is required. This can be accomplished with six extraction Lambertsons placed below the present main ring Lambertsons. The extraction channel will require 4 C-magnets and 14 H-magnets rather than two and seven presently in use. No vertical bending magnet will be required in the Tevatron extraction channel. The first vertical bend occurs at MVT90 which is used to adjust the proton split ratio. Quadrupoles MQ90 and MQ91 will be moved downstream of the splitting station into the transfer hall extension to make room for the additional magnets required in the extraction channel.

Also, required in the transfer hall extension is a switching magnet that will cancel the 5 mr vertical rise of the Tevatron beam and correct the 1 mr horizontal angle placing the beam into the present switchyard channel. This magnetic switch is conceivably a 22-foot Doubler magnet or two conventional main ring dipoles.

III. Proton Beam Line

The first modification that must be made to the proton beam line occurs at the electrostatic septa for the proton split. In order to maintain the present beam separation at the proton Lambertsons the number of septa must be increased from three to six with the three additional septa reaching into the transfer hall extension (Fig. 2). There is adequate space for the septa, MQ90, MQ91, and 2 twenty-foot dipoles which make up the magnetic switch mentioned above.

The Tevatron beam joins present switchyard beam line in the transfer hall extension just upstream of the proton Lambertsons, MH300, therefore a new set of Lambertsons is not required. However, it is necessary to achieve a 6.5 mr bend in the Lambertsons at 1000 GeV. This can be done by adding 2 more Lambertsons downstream of the present set of 5 and by running all of them at approximately 2000 amps instead of the 1200 amps they run at now. The beam line correction for moving the bend center downstream is made at the right bends. The use of more Lambertsons at less current is ruled out by the maximum beam separation permissable within the magnets, however there is an alternative. The number of Lambertsons can remain at 5 with the addition of 5 downstream H-magnets. This requires a total current of only 1000 amps through the Lambertsons and H-mangets. Again movement of the bend center must be accounted for downstream.

The right bends begin in Enclosure B and continue into Enclosure D. They account for a total horizontal bend of 77 mrads which can easily be made using 11 Doubler magnets running at 35 KG. These magnets replace 16 EPB dipoles in Enclosure B and 18 EPB dipoles in Enclosure D. The 11 superconducting magnets will be placed in 2 continuous sections, 5 in Enclosure B and 6 in Enclosure D. Twenty-two foot Doubler magnets can be put into Enclosure B through the transfer hall, however an access shaft must be constructed at the downstream end of Enclosure D to admit Doubler magnets. One such shaft has already been constructed in the meson beam line and will be described in the meson section.

Quadrupoles which are now interspersed in the two bend sections will be moved to either end of the string to minimize the complications arising from breaking the superconducting string. MQ301 is moved downtream 80 feet to the end of the first section and MQ304 is moved downstream 30 feet to the end of the second bend section.

Other changes necessary in the proton beam line will be to increase the number of conventional quadrupoles and trim magnets to provide additional focusing and bending power at 1000 GeV. There will be adequate room for this change everywhere except at MQ302. At that location an additional five-foot quadrupole can be added to achieve the required focusing. It will be necessary to move MQ310 and MQ311 130 feet upstream in order to make room for the additional splitting septa, trims and vertical bending magnets in Enclosure E (Fig. 3), which will be required to maintain the three-way split. Five additional septa will be required as well as 3 additional B1 magnets for the vertical bends, MV310. The space for these changes is obtained by moving beam line elements into the drift space at the upstream end of Enclosure E. Enclosure H modifications are being designed by the Proton Department and the details can be found in Reference 1. Table I is a summary of the additional proton beam line elements required to reach 1000 GeV.

IV. Neutrino Beam Line

Necessary modifications to the neutrino beam line are detailed in TM-796. Those details will be briefly reviewed here. The primary change is the addition of a muon beam line which will necessitate a new splitting station beginning just downstream of the meson split. To accommodate this split a new enclosure must be added along side the upstream end of Enclosure C (Fig. 4). The new enclosure will house 60 feet of electrostatic septum which will introduce a .22 mrad horizontal deflection between the N0 beam and the new muon beam, MU0. Five 10-foot Lambertson magnets for the split will be placed in the G1 manhole and the existing G1 quadrupole doublet and drift space will be removed. At this point the MU0 beam is bent down 2.7 mrad.

The vertical bend, MV100, will be made with 70 feet of main ring B2-type magnets running at 16 KG. These magnets will be located upstream of the new splitting station with the bend center moved approximately 10 feet from its present location.

The beams enter the G2 manhole with the MU0 beam coming in 17.8 inches below the N0 beam line and 2.44 inches to the east. At this point an 8.55 mr downward bend and a 33.5 mrad bend to the east is introduced in MU0. This can be done with four 22-foot Doubler magnets running at 43 kG. Accommodation of this bend requires lengthening of the G2 manhole by about 100 feet to the north. The MU0 and the N0 beams pass through quadrupole doublets in G2 which are each made up of 4 3Q120's.

From G2 the MU0 beam drifts to a target located approximately half way between Neuhall and the target service building. A buried beam pipe along side the neutrino berm and possibly 1 quad enclosure will deliver the beam from G2 to Muhall. The details of this transport will be described in a subsequent report by the Neutrino Department.

The G3 manhole will contain a quadrupole doublet for the N0 beam as well as some horizontal trim magnets (EPB dipoles) which coupled with some additional EPB dipoles located in G2 will correct for the .11 mrad horizontal angle introduced at the electrostatic septa. The electrostatic septa now present in G3 and used for the N7 split will be removed as the N7 bypass line will be discontinued.

Neuhall will contain the downstream string of B2 dipoles which form the second half of the MV100 vertical bend as well as the pre-target triplet which is made up of six 3Q120's. Room is also available for a set of trim magnets which will be necessary for targeting the beam. Table II summarizes the beam line elements required for the neutrino line upgrade.

V. Meson Beam Line

The meson beam line begins with the electrostatic septa located in the downstream end of Enclosure B. The number of these septa must be increased from three to six to attain adequate beam separation at the meson Lambertsons which are located 280' downstream at the beginning of Enclosure C (Fig. 4). This can be done by placing three additional septa downstream of the three existing septa. At 1000 GeV these septa will impart a .14 mrad deflection between the neutrino beam and the meson beam which will result in a .4" separation at the meson Lambertsons.

As at the proton split, the Lambertsons will be followed by 5 C- or H-magnets to provide an 11 mrad bend. The two EPB dipoles, MH201-1 and MH201-2 will be left in their present positions to serve as horizontal trims, and to allow 400-GeV beam to be delivered to the Meson Area through a superconducting left bend without the addition of the C-magnets following the Lambertsons. The left bends begin at the location of MH201-3 with a ten magnet continuous string that ends at MH202-4. MQ201 is placed immediately downstream of the superconducting string and will be made up of two 3Q120's (Fig. 4). MQ202 also moves downstream about 40 feet and becomes two 3Q120's. MQ203 retains it's present position but becomes two 3Q120's instead of one (Fig. 5). MQ204 must be moved upstream 40 feet to allow the second string of superconducting Doubler magnets to begin at the present location of MH203-4 (Fig. 5). This string consists of eleven Doubler magnets which ends at MH203-25 leaving adequate space to increase the number of magnets in the upstream MV204 vertical bend string from 4 to 8. Quads MQ205 and MQ206 remain at their positions before and after MV204, however it is not necessary to double their lengths.

In order to put the 22-foot Doubler magnets into Enclosure C it was necessary to construct an access shaft. The shaft is located about 20-feet downstream of MQ203 and comes directly into the top of the switchyard tunnel. The dimensions of the shaft are 14' x 5' which means that the magnets must be suspended at approximately 45 degrees to be placed in the tunnel. This method has been successfully tested and two Doubler Magnets have already been placed in the tunnel.

The 22 Doubler magnets must make a 9° horizontal bend. This is done by running them at 37 kG for 1000-GeV beam or at 15 kG for 400-GeV beam. Both sections of the bend will be powered in series.

A two-way split[3] in the meson beam line begins in the F1 manhole with two electrostatic septa which give a 45 μrad deflection between the two beams. The two quadrupoles MQ-210 and MQ211 will remain in F1 along with the septa. Three Lambertson magnets for the split will be located 1000 feet downstream of the septum in the F3 manhole. The two quadrupoles MQ230 and MQ231 presently located in F3 will be removed as well as MQ220 and MQ221 located in the F2 manhole. Initially the split will be constructed to operate at 400 GeV only. During this period there will be only one electrostatic septum in F1 and 2 Lambertson magnets in F3.

The two independent beam lines will enter Meshall separated horizontally by 16 inches which will allow ample room for the placement of two sets of magnets side-by-side. The two beam lines will each be similar to the present beam line which consists of the top half of the vertical bend, MV204, and a focusing triplett. To accommodate the large horizontal separation of the two beams before they reach Meshall a 48" pipe will be installed between the F3 manhole and Meshall.

The construction required to attain 1000 GeV includes the lengthening of the F1 manhole by about 30 feet to make room for additional quadrupoles to supplement MQ210 and MQ211. It will also be necessary to extend Meshall upstream by 75 feet to accommodate the vertical bends which will remain conventional.

Further details of the splitting modifications can be found in Reference 3, and the additional beam line elements required are summarized in Table III.

VI. <u>Cryogenic Components for the Switchyard</u>

Liquid helium for the right and left bends will be supplied by the Switchyard satellite refrigerator located in the Switchyard Service Building. The subcooled liquid will be transported to the dipoles through coaxial transfer lines which also return the two-phase helium, carries liquid nitrogen for the shield, and contains the superconducting leads. The transfer lines enter the tunnel through an existing penetration in the floor of the Switchyard Service Building. The entry point is in the crossover tunnel at the G1 manhole.

The left bend transfer line enters Enclosure C and splits at a Tee box to serve both the upstream and downstream bend sections. The right bends will be serviced through the bypass tunnel at the downstream end of Enclosure D. The longest path for the left bends is 250 feet to the upstream section. The right bends will require approximately 600 feet of transfer line if they are serviced entirely from the Switchyard Service Building. An alternative that would save two to three hundred feet would be to cool the upstream bend section using a refrigerator located near the end of the transfer gallery. One hundred and fifty feet of the transfer line to the left bends area is presently under construction in order to carry out a test of two Doubler magnets in the meson beam line.

VII. Schedule for Switchyard Upgrade

Current plans call for the switchyard upgrade to begin immediately. The first step will occur during mesopause and will entail replacing the fifty-six EPB dipoles that make up the left bends with twenty-two Energy Doubler/Saver magnets as described above. Work is underway now to install two Doubler magnets in the meson beam line in the drift space in Enclosure C. These magnets are to be run with opposing fields so as not to disturb Meson Laboratory operations between June and August 15, the scheduled shutdown date for the Meson Lab.

Upon successful completion of the two magnet test replacement of the left bends will begin during the August 15, to October first shutdown. All magnets should be installed and ready for operation by January, 1979, when the Meson Laboratory is scheduled to resume operation. As pointed out above, additional C-magnets, doubling of quadrupoles and electrostatic septa will not be necessary at this time. These changes can be made one step at a time over the next two years.

Also to be done during mesopause is the installation of the two-way split. This work will be carried out simultaneously with the left bends project.

Neutrino beam line modifications will begin during the Summer of 1979 with the construction of the new enclosure to house the electrostatic septa for the muon split and the lengthening of the G2 manhole for the horizontal bend in MUO. The neutrino upgrade will be completed in Fiscal Year 1979.

Proton beam line upgrade will be done in 1980 with replacement of the right bends and modifications to the proton splitting station being the major tasks.

A summary of the construction necessary to reach 1000 GeV is shown in Table IV. Also to be found in Table IV are the construction items necessitated by the additional splitting stations in m lines.

References

1. B. Cox, P. Garbincius, J. Lach, T. Murphy, K. Stanfield; Proton Laboratory 1 TeV Upgrade; March, 1978.

2. R. Evans, T. Kirk, TM-796; May, 1978.

3. A. Jonckheere, Meson Primary Proton Beam Targeting Upgrade; March, 1978.

TABLE I - Additional Elements Required for
1000 GeV Proton Beam Line

Electrostatic Septa

PSEP4-6	Additional for Proton/Neutrino Split
ES10 C&D	Additional for Proton 3-way Split
ES11 C&D&E	Additional for Proton 3-way Split

Total = 8

Doubler Magnets

MH302-1-5	Right Bends
MH303-1-6	Right Bends

Total = 11

Quadrupoles

MQ300B-305B	Additional Focusing
MQ310B-311B	Additional Focusing

Total = 8

EPB Dipoles

MHT-1-2	Additional Horizontal Trimming

Total = 2

Main Ring B1 Dipoles (10 foot)

MV310-4-6	Vertical Bends

Total = 3

40" Trims

MVT301B	Additional Vertical Trimming
MHT305B	Additional Horizontal Trimming
MVT308B	3-way Split Adjustment
MVT310C&D	3-way Split Adjustment
MVT311C&D	3-way Split Adjustment
MHT310	Additional Horizontal Trims

Total = 8

H-Magnets

MH300-6-10	Additional Proton/Neutrino Split

Total = 5

TABLE II - Additional Elements Required for 1000 GeV Neutrino Beam Line

Electrostatic Septa

MUSEP1-6	Muon Split

Total = 6

Lambertson Magnets

MH400-1-5	Muon Split

Total = 5

Doubler Magnets

MH401-1-4	Muon Horizontal/Vertical Bend

Total = 4

Quadrupoles

MQ100B	Additional Focusing
MQ101B	Additional Focusing

Total = 2

Main Ring B2 Magnets (10 foot)

MV100-1-7	Vertical Bends
MV140-1-7	Vertical Bends

Total = 14

EPB Dipoles

MVT105	Muon Split Adjust

Total = 1

40" Trims

MVT100B-103B	Additional for Meson/Neutrino Split

Total = 4

TABLE III - Additional Elements Required for Meson Beam Line

Doubler Magnets

MH202-1-10	(Left Bends)
MH203-1-12	(Left Bends)

Total = 22

Electrostatic Septa

MSEP4-6	(Meson/Neutrino Split)
ES210-1-2	(Meson Split)

Total = 5

Quadrupoles

MQ201-4B	(Additional Focusing)
MQ252-8	(Additional Beam Line)
MQ262-8	(Additional Beam Line)

Total = 17

Deleted Quadrupoles

MQ220
MQ221
MQ230
MQ231

Total = 4
Net Quadrupoles Increase = 13

40" Trims

MVT201	Additional Vertical Correction
MVT202	Meson Split Adjustment
MHT204	Additional Horizontal Correction
MVT210, 211	Meson Split Adjustment
MVT230, 231	Meson Split Adjustment
MHT250	Additional Horizontal Trim
MHT260	Additional Horizontal Trim

Total = 9

EPB Dipoles

MHT201-1-2	Additional Horizontal Trim
MV204-5-8	Additional Vertical Bends
MV240-5-8	Additional Vertical Bends
MV250-5-8	Additional Vertical Bends

Total = 14

C-Magnets

MH300-6-10	Meson/Neutrino Split Magnets

Lambertson Magnets

MH330-1-3	Meson Split

TABLE IV - Summary of Required Switchyard Construction

Proton Area

1)	Access Shaft - Enclosure D	For installating Doubler magnets.

Neutrino Area

1) New enclosure along side C to house electrostatic septa for muon split.

2) Extend G2 manhole 100 feet to north to house horizontal bends for muon split.

Meson Area

1) Access shaft in Enclosure C for installing Doubler magnets.

2) Extend Meshall south by 75 feet to accommodate 3-way split.

3) Install 48" pipe between F3 and Meshall for 3-way split.

4) Lengthen F1 by 30' to accommodate quadrupoles and electrostatic septa for 3-way split.

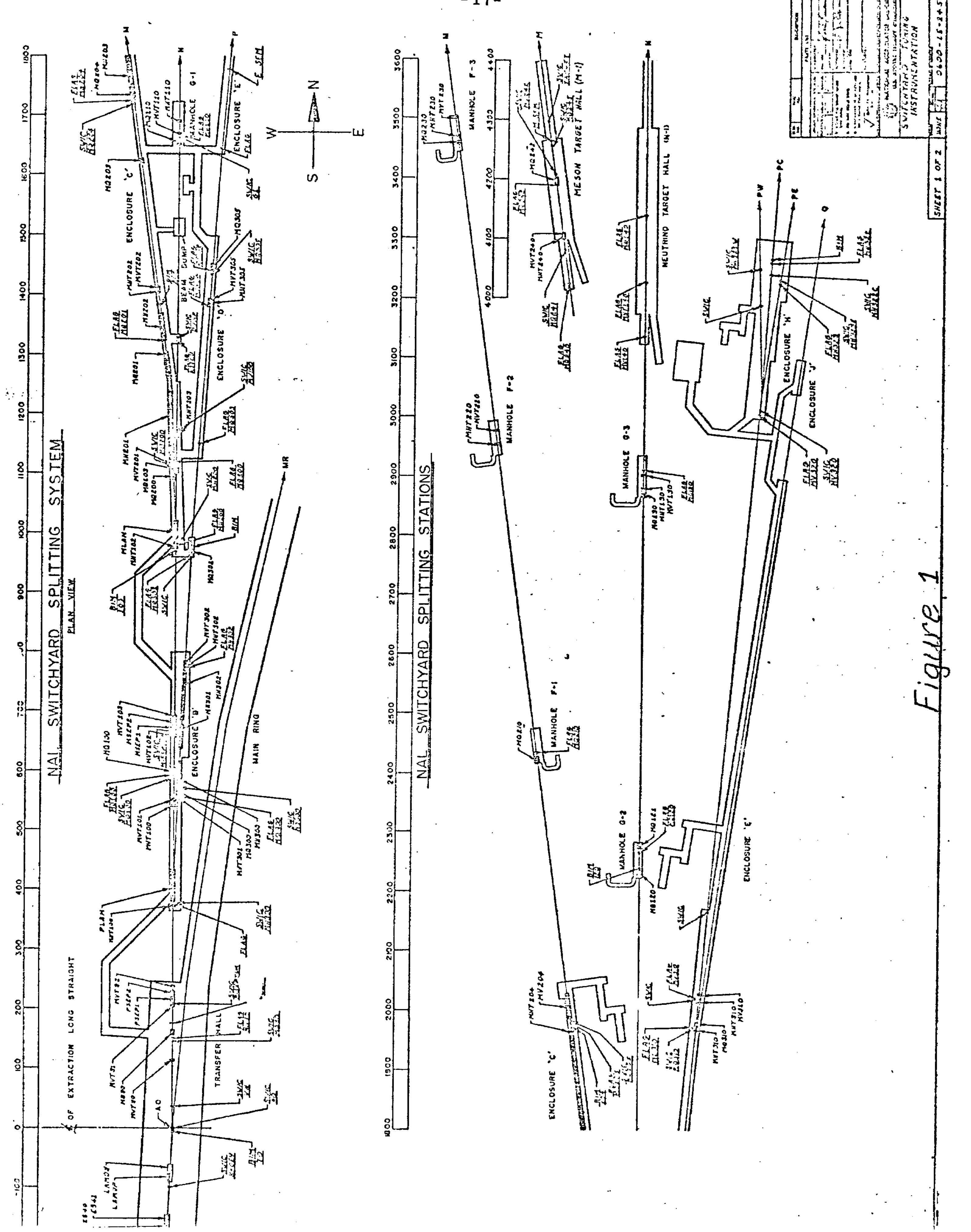
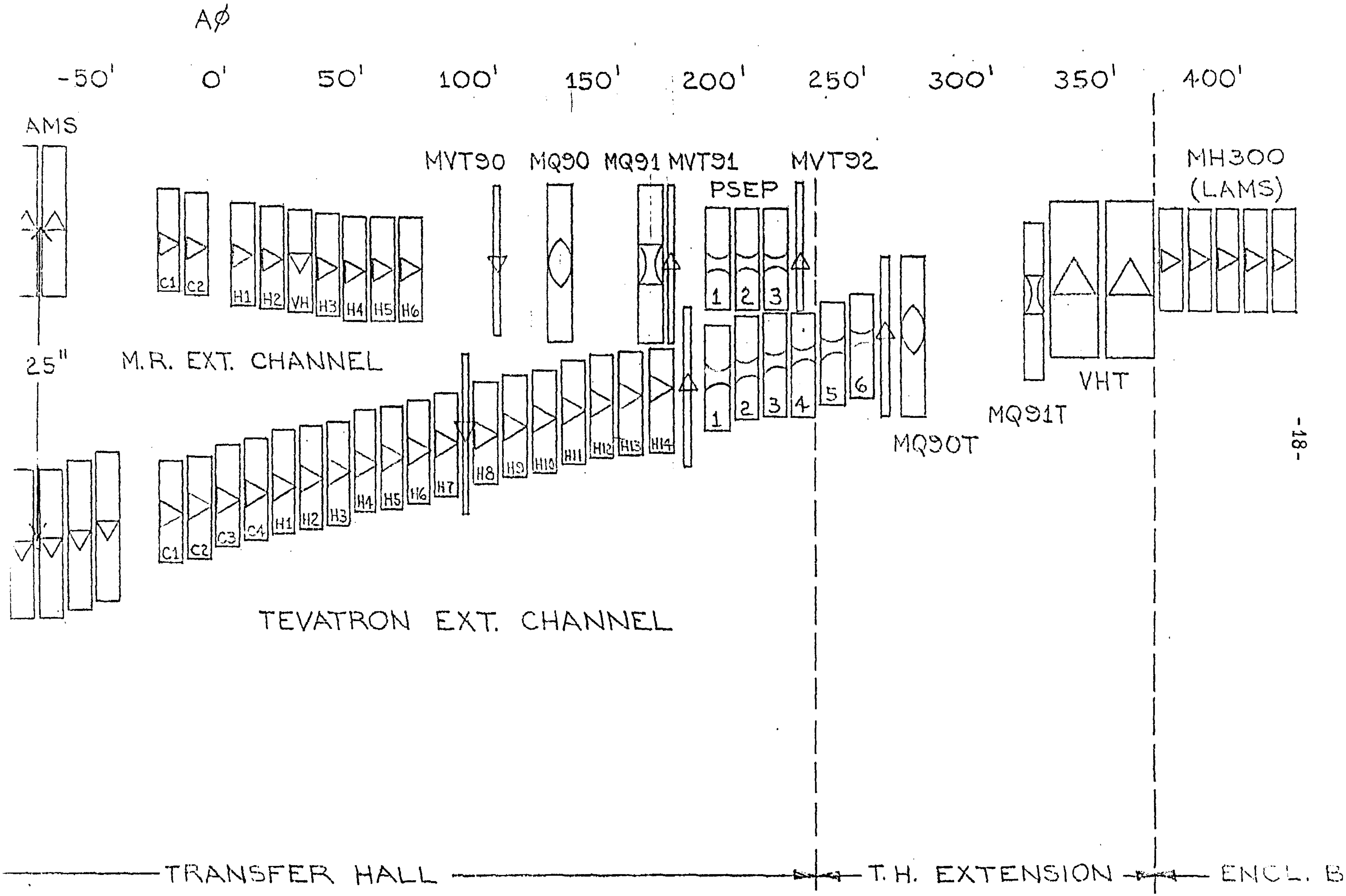

NAL SWITCHYARD SPLITTING SYSTEM
PLAN VIEW
NAL SWITCHYARD SPLITTING STATIONS
EXTRACTION LONG STRAIGHT
TRANSFER HALL
MAIN RING
ENCLOSURE 'B'
ENCLOSURE 'C'
ENCLOSURE 'D'
ENCLOSURE 'E'
BEAM DUMP
MANHOLE G-1
MANHOLE G-2
MANHOLE G-3
MANHOLE F-1
MANHOLE F-2
MANHOLE F-3
MESON TARGET HALL (M-1)
NEUTRINO TARGET HALL (N-1)
ENCLOSURE 'H'
ENCLOSURE 'J'
SWITCHYARD TUNING INSTRUMENTATION
SHEET 1 OF 2

Figure 1



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H6
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MQ91T
MQ90T
C1
C2
C3
C4
H1
H2
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H5
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H7
H8
H9
H10
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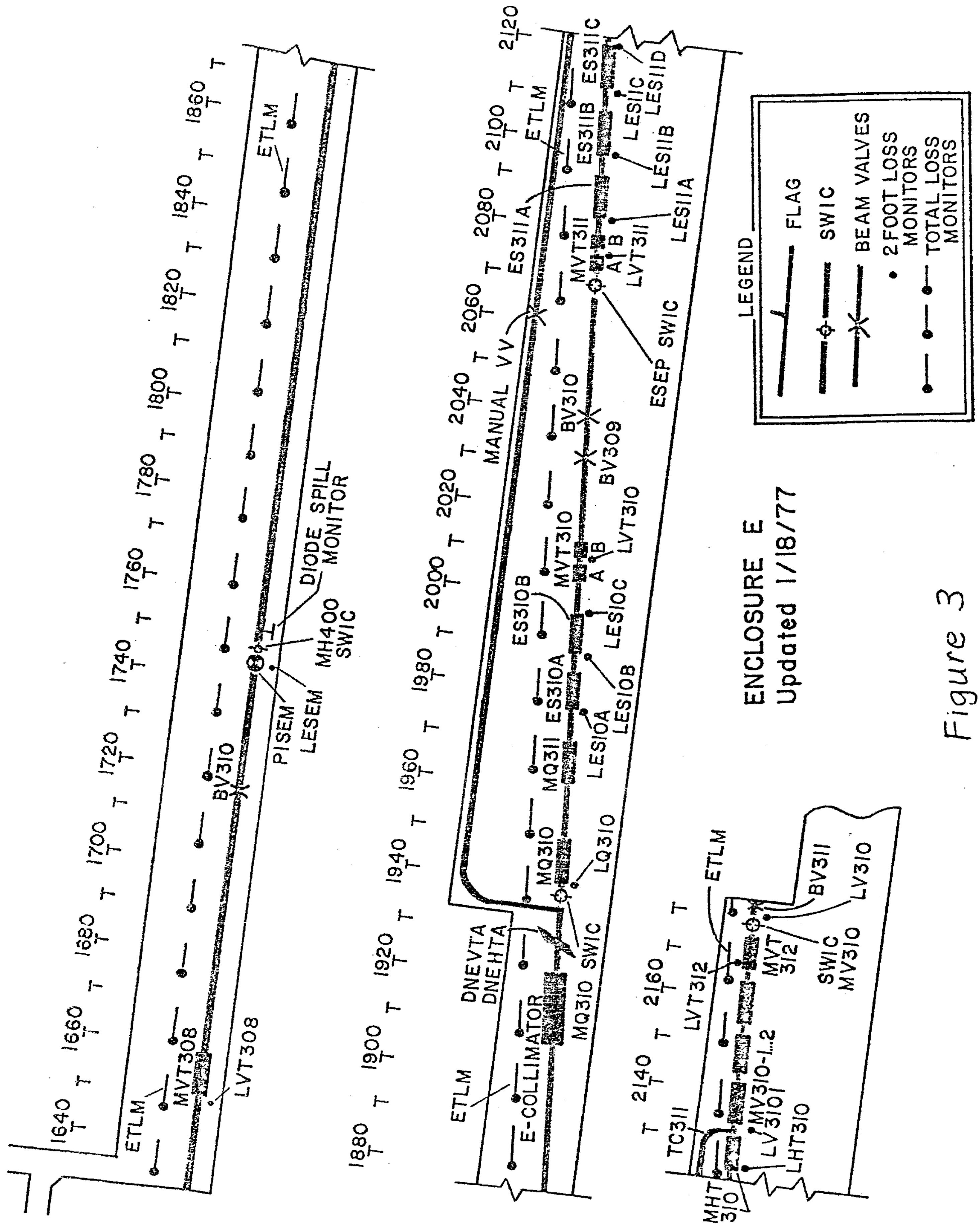
H12
H13
H14
TEVATRON EXT. CHANNEL
TRANSFER HALL
T.H. EXTENSION
ENCL. B

Figure 2


ENCLOSURE E
Updated 1/18/77
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MVT308
LVT308
BV310
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LESEM
MH400
SWIC
DIODE SPILL MONITOR
E-COLLIMATOR
DNEVTA
DNEHTA
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SWIC
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LES10A
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LES10C
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LVT310
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BV310
MANUAL VV
ESEP SWIC
MVT311
LVT311
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LES11D
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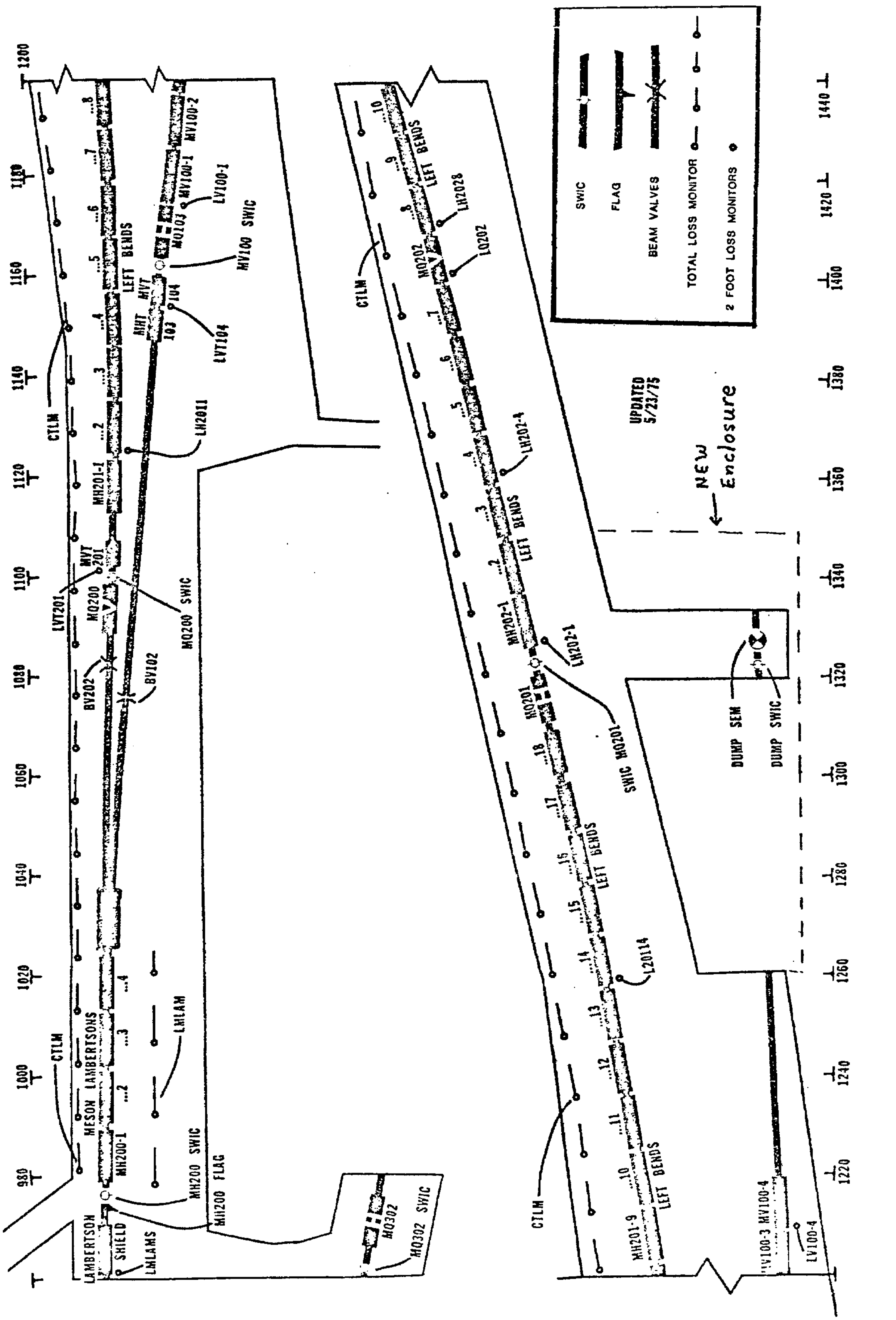
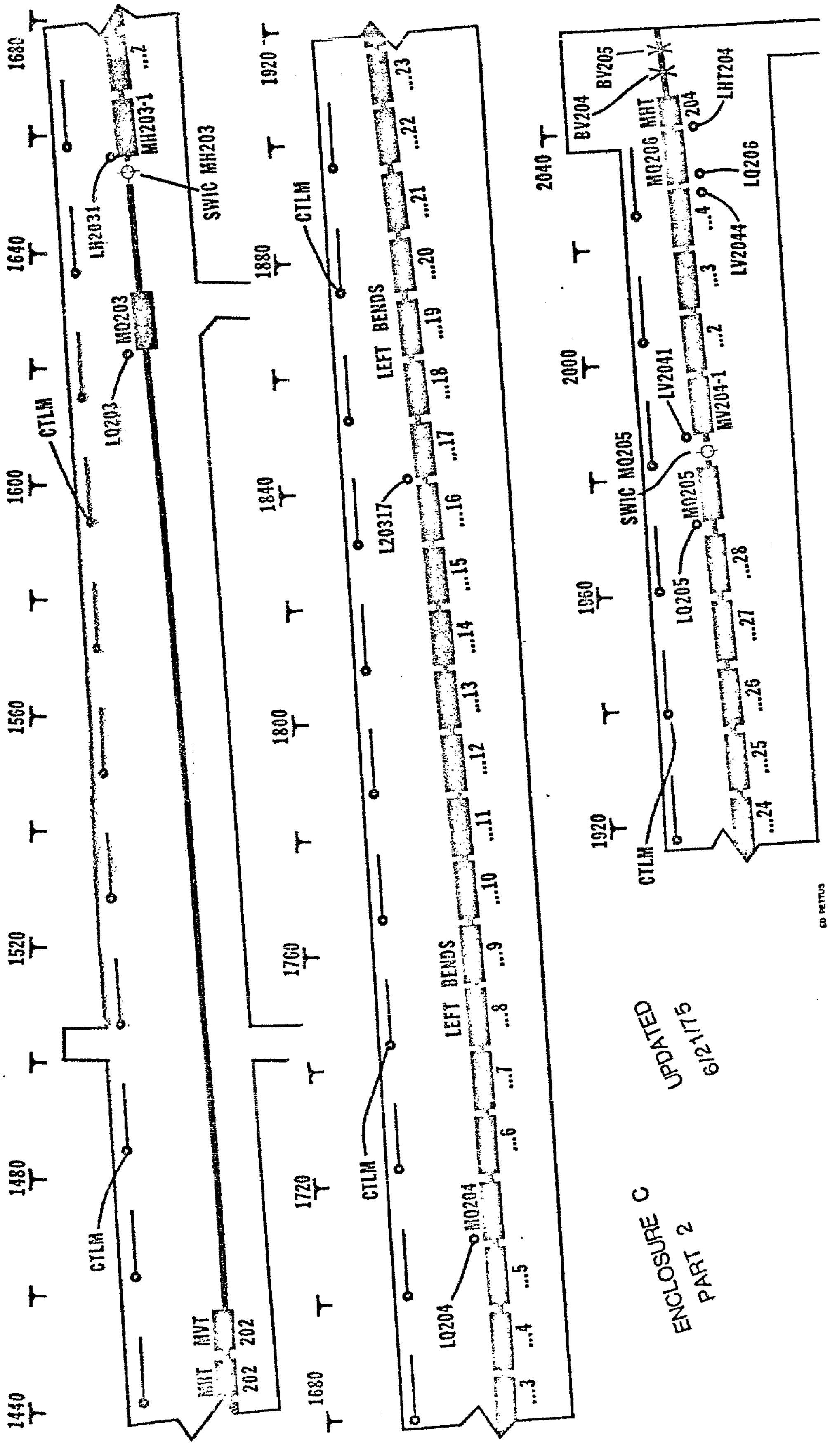
LV310

Figure 3



ENCLOSURE C
PART 1

Figure 4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LQ203
MHT MVT
202 202
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LQ204
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LEFT BENDS
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BV204
BV205
LHT204
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MV204-1
SWIC MQ205
MQ205
LQ205
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ENCLOSURE C
PART 2
UPDATED
6/21/75

Figure 5

High Luminosity pp Colliding Beam Straight Section

D.E. Johnson

A matched, low beta long-straight section applicable to proton-proton collisions has been designed for the current version of the doubler lattice and is described below. This straight section has a central free space of some 155 feet, into which the so-called "kissing" magnets can be installed along with a central detector. This straight section involves four, separately powered quadrupole circuits, and is capable of producing adiabatically a β^* of from several hundred meters down to one meter. Results of simple chromaticity corrections for lattice including this straight section are presented, and do not appear unfavorable.

A long-straight section, similar to previous straight section[1], has been designed for the latest doubler lattice. It is shown in Fig. 1. This has been designed primarily for pp collisions, so one constraint was to leave as much free space as possible. In addition, it has been designed to reach a β^* of one meter, thus influencing the quadrupole lengths. The design consists of replacing the inner doubler quadrupoles with much longer, three-shelled quadrupoles, replacing the quadrupoles at the 48 and 12 locations with a new, three-shelled quad, and putting the existing quadrupoles at 47 and 13 on a separate power supply. The quadrupoles are then powered antisymmetrically on four circuits, A-D, as shown in Fig. 1. A list of quadrupole strengths for various β^*'s is shown in Table I, and a plot of beta and η across the straight section is shown in Fig. 2.

β^*(m)	A(kG/m)	B(kG/m)	C(kG/m)	D(kG/m)
60	-651	813	-511	429
40	-696	913	-603	517
20	-659	972	-758	729
10	-529	880	-842	875
5	-306	657	-877	953
3	-50	440	-887	987
2	192	317	-891	1002
1	633	259	-900	1011

Table I

Various machine parameters for different values of β^* are listed in Table II. The tunes given are those before correction in the rest of the lattice, and are listed to give a feel for the amount of correction needed. It should be noted in Table II that β_{max} for large values of β^* comes from the high-beta sections put in for extraction.

β^*(m)	η^*(m)	β_{max}(m)	$\lvert\eta_{max}$(m)$\rvert$	Q_x	Q_y	ξ_x
60	2.15	235	7.1	19.358	19.396	-22
39	1.31	243	7.5	19.447	19.485	-22
20	0.94	242	8.4	19.556	19.593	-23
10	0.86	250	9.4	19.598	19.637	-23
5	0.83	501	10.7	19.618	19.661	-26
3	0.83	850	12.0	19.649	19.697	-27
1	0.78	2467	22.0	19.720	19.793	-37

Table II

The major objections to this low-beta design are

1. That beta and eta get as large as they do, and for the one-meter case in particular, that they occur at the same position; and
2. That the dispersion function changes not only in the straight section, but around the entire ring and may cause problems with chromaticity corrections, etc.

It is difficult to completely respond to these objections as they are in general so nonlinear. Some statements can be made, however.

The simplest question is that of beam size. In the normal doubler lattice, without a low-beta straight section, the maximum beam size is determined by the following:

at the high-beta points	$\beta_x = 235$ m, $\eta_x = 3.5$ m
in the rest of the lattice	$\beta_x = 97.9$ m, $\eta_x = 6.57$ m

There are two, high-beta locations and 18 other maximum beam size positions in the entire ring. With a low-beta section set for β^* of one meter, the maximum sizes come from:

in insertion	$\beta_x = 2467$ m, $\eta_x = -22$ m
in the rest of lattice	$\beta_x max = 108$ m, $\eta_x max = 10.8$ m.

There is only one large beam position in the spaced straight section, and while there are still 18 of the other maxima, they are all either equal to or less than the one listed, as the dispersion is not usually as large as eleven meters. In any event, if injection is at 100 GeV, the low-beta section is turned on at 1 TeV and normal damping occurs between the two energies, the one large beta large eta point will fit within the injection aperture and the beam in the rest of the lattice will be well within the aperture. It may be necessary to locally correct the beam at its one extreme position in order to improve lifetime, but that should be possible.

The other problem with the large value of beta is that all resonance phenomena increase with beta. Hence, it again may be necessary to locally correct the field in these large quadrupoles. In addition, the power supply ripple and regulation must be very accurately controlled.

In an attempt to answer the second question, chromaticity corrections were made for this lattice for various values of β^*. The most straightforward and simple correction case was considered - that is to use 30 sextupoles per sector, have all the sextupoles grouped into two families, so-called F and D sextupole families, and set the natural chromaticity for the on-momentum ray to about zero for each plane. The results of this program are presented for the cases of β^* of 3.5 and 1 meters. In the 1 meter case, an effort to re-establish the times to 19.4 was not made, rather the corrections were made to the original value of 19.7, and are intended to simply show the nature of the worst case.

A problem with chromaticity corrections is the lack of a uniform dispersion wave around the ring for small values of β^*. This can be seen in Figs. 3-6. Here is plotted the dispersion function on a large scale as a function of position around the ring for different values of β^*. By the time β^* gets down to a few meters, there are so many places that the dispersion is either zero or negative, that the effectiveness of uniformly-placed sextupoles is reduced and so their strengths must increase.

Chromaticity corrections for all values of β^* down to approximately five meters is very straightforward and causes no problems. Corrections for the case of $\beta^* \simeq 3.5$ m were studied in detail and appear to present no significant problems. Plots of beam parameters versus momentum deviation for this case are shown in Figs. 7-10. There is a rather large spread of $\Delta\beta/\beta$ vs. $\Delta p/p$, but this should not be serious for the momentum spread contemplated. Certainly the change of luminosity due to the change of β^* is negligible, and the resonance corrections at the beta-max point should not be too difficult. The same quantities have been examined for the case of a low-beta of one-meter, and are plotted in Fig. 11-14. Although in this case, the overall tune of the machine has not been readjusted to 19.4, the results are shown quite similar to those at the tune of 19.4, and again do not indicate major problems.

Perhaps the most serious difficulty with these chromaticity corrections is that, as the dispersion function is so non-regular the necessary sextupole strengths using only two families in series, is somewhat larger than it might be otherwise. The values which have been used are:

for $\beta^* = 3.5$ m

$$(B''\ell)_F = 432 \text{ kG/in}$$

$$(B''\ell)_D = -750 \text{ kG/in}$$

and for $\beta^* = 1$,

$$(B''\ell)_F = 617 \text{ kG/m}$$

$$(B''\ell)_D = -1089 \text{ kG/m} .$$

Other phenomena still need to be studied, such as the excitation of higher-harmonic resonances, the coupling with closed-orbit errors, etc., and the results may easily lead to a more complicated correction system involving many different sextupole circuits, but so far the most straightforward scheme would seem to be adequate.

1. D.E. Johnson, "Main Ring/Doubler Low-Beta Insertions", 1977 Summer Study, Fermilab

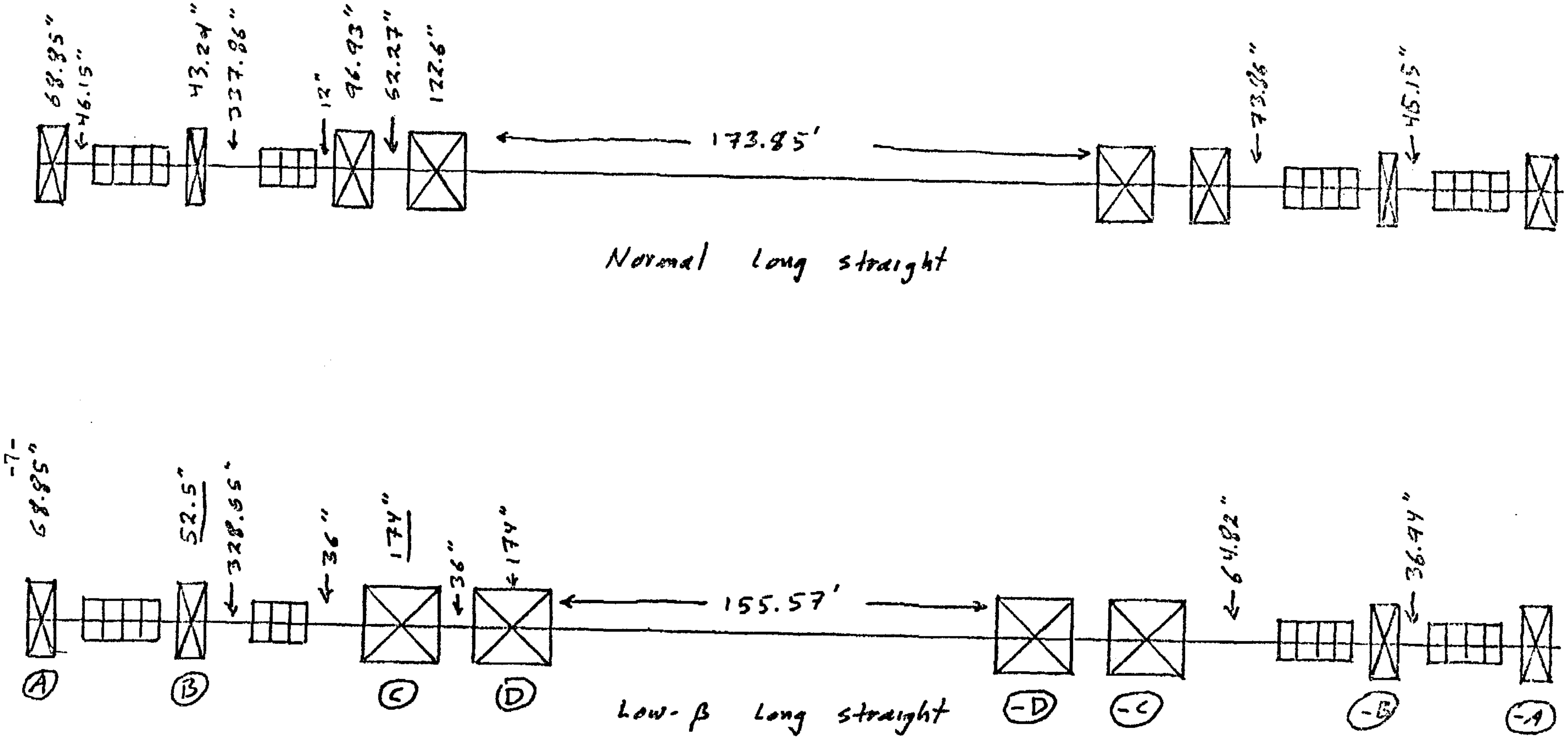
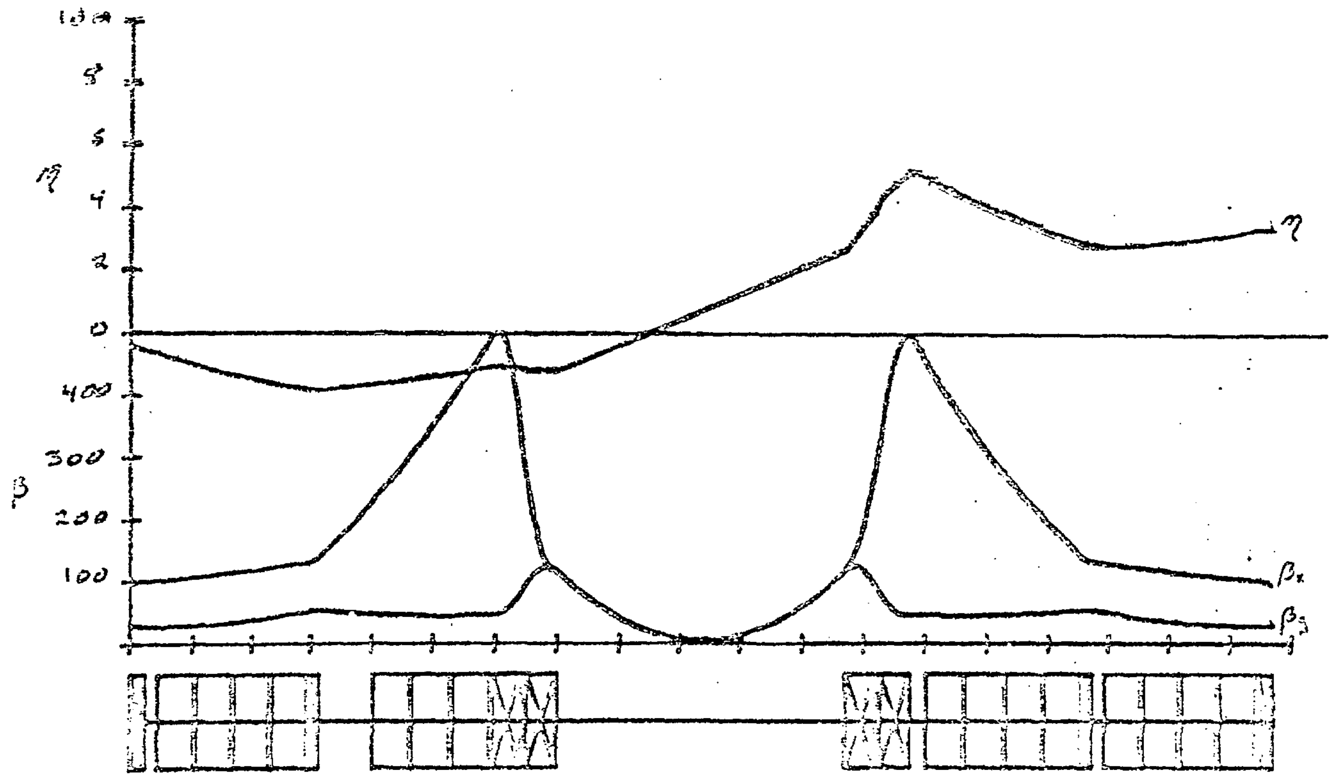

68.85"
46.15"
43.24"
337.86"
12"
96.93"
52.27"
122.6"
173.85'
73.86"
45.15"
Normal long straight
68.85"
52.5"
328.55"
36"
174"
36"
174"
155.57'
64.82"
36.94"
A
B
C
D
-D
-C
-B
-A
Low-β long straight

Figure 1



$\beta^* = 5$ m

Figure 2

Doubler η-fun. with 1 low-β &
2-high-β sections
$\beta^* \approx 60m$

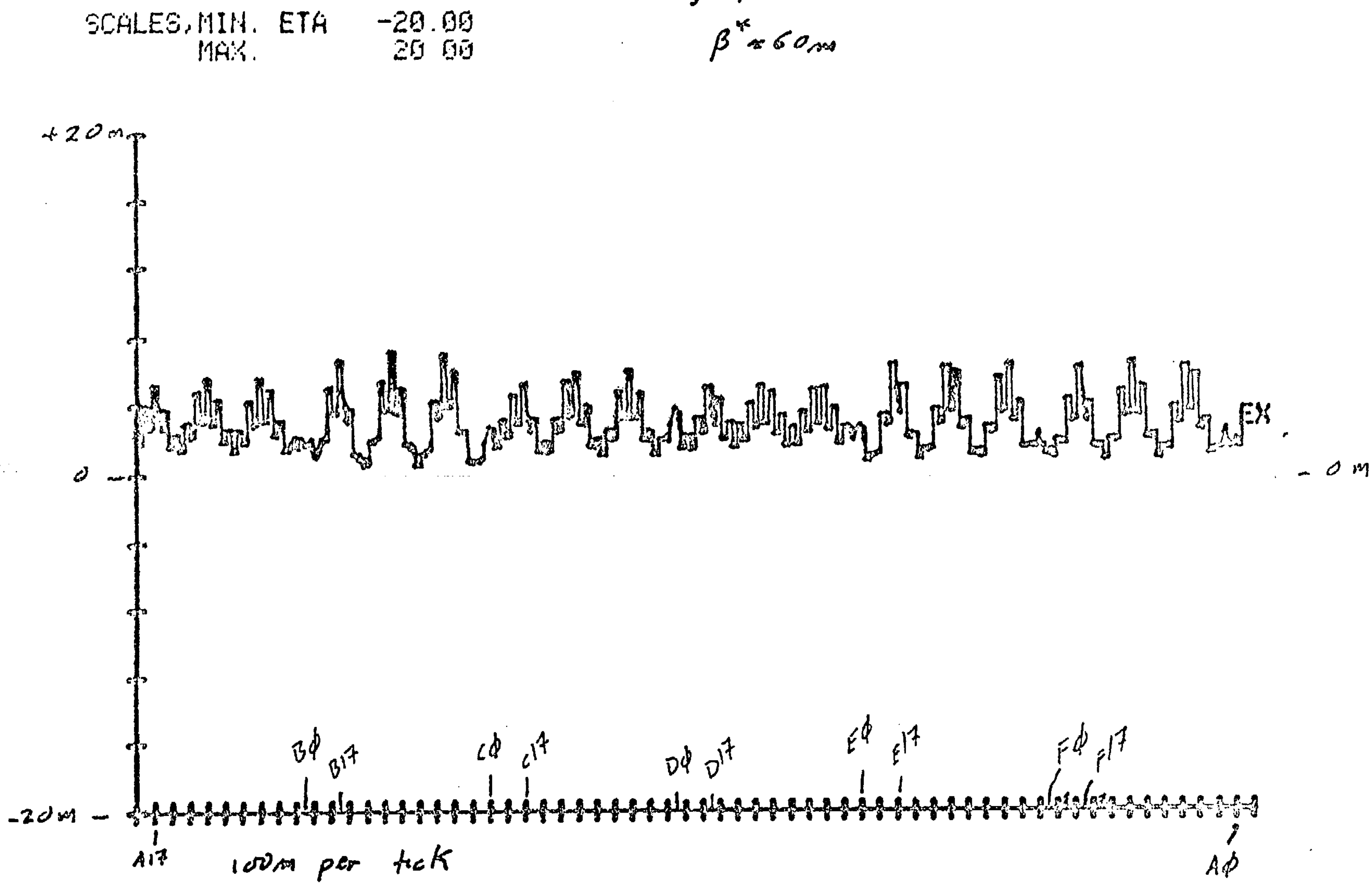


Figure 3

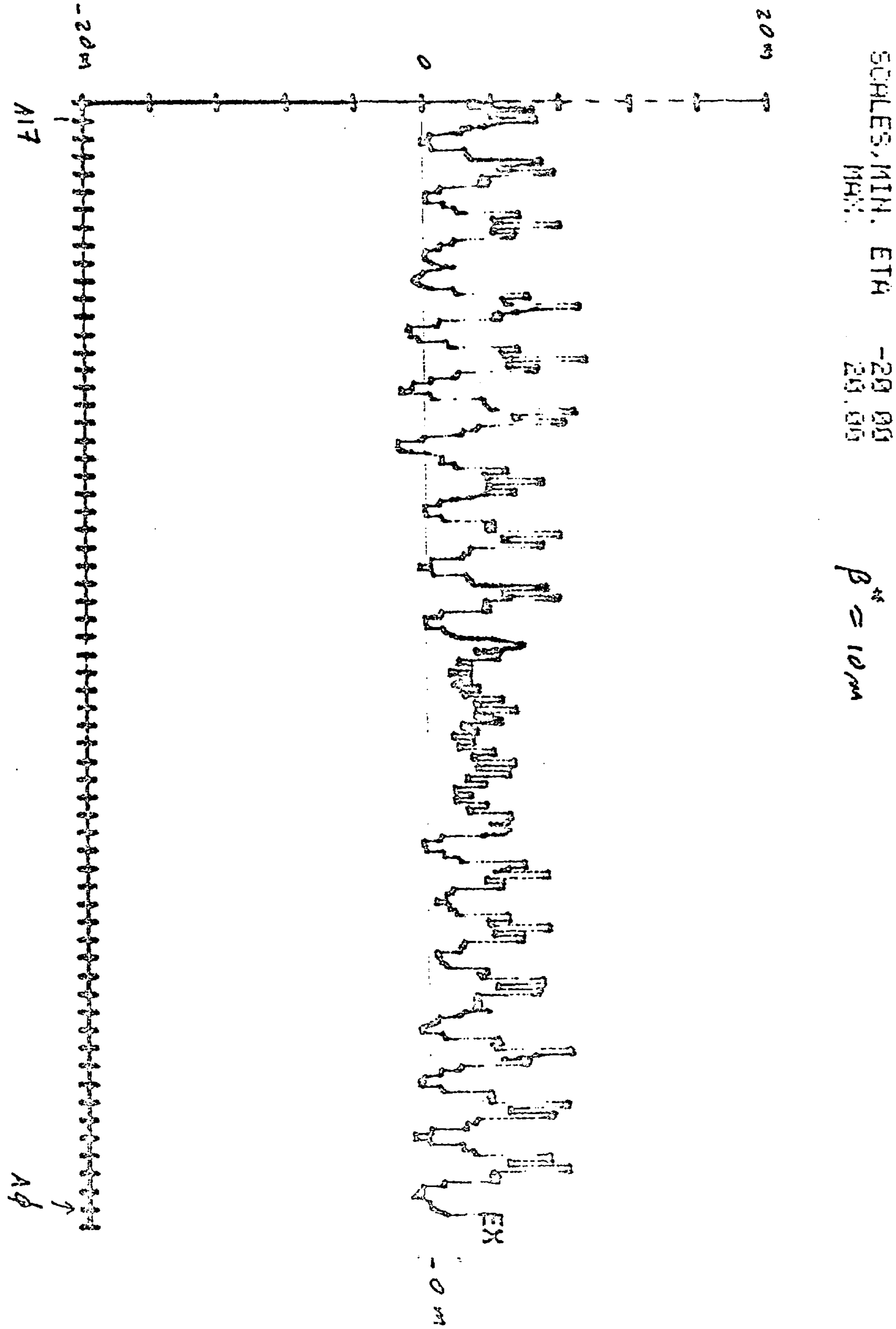


Figure 4

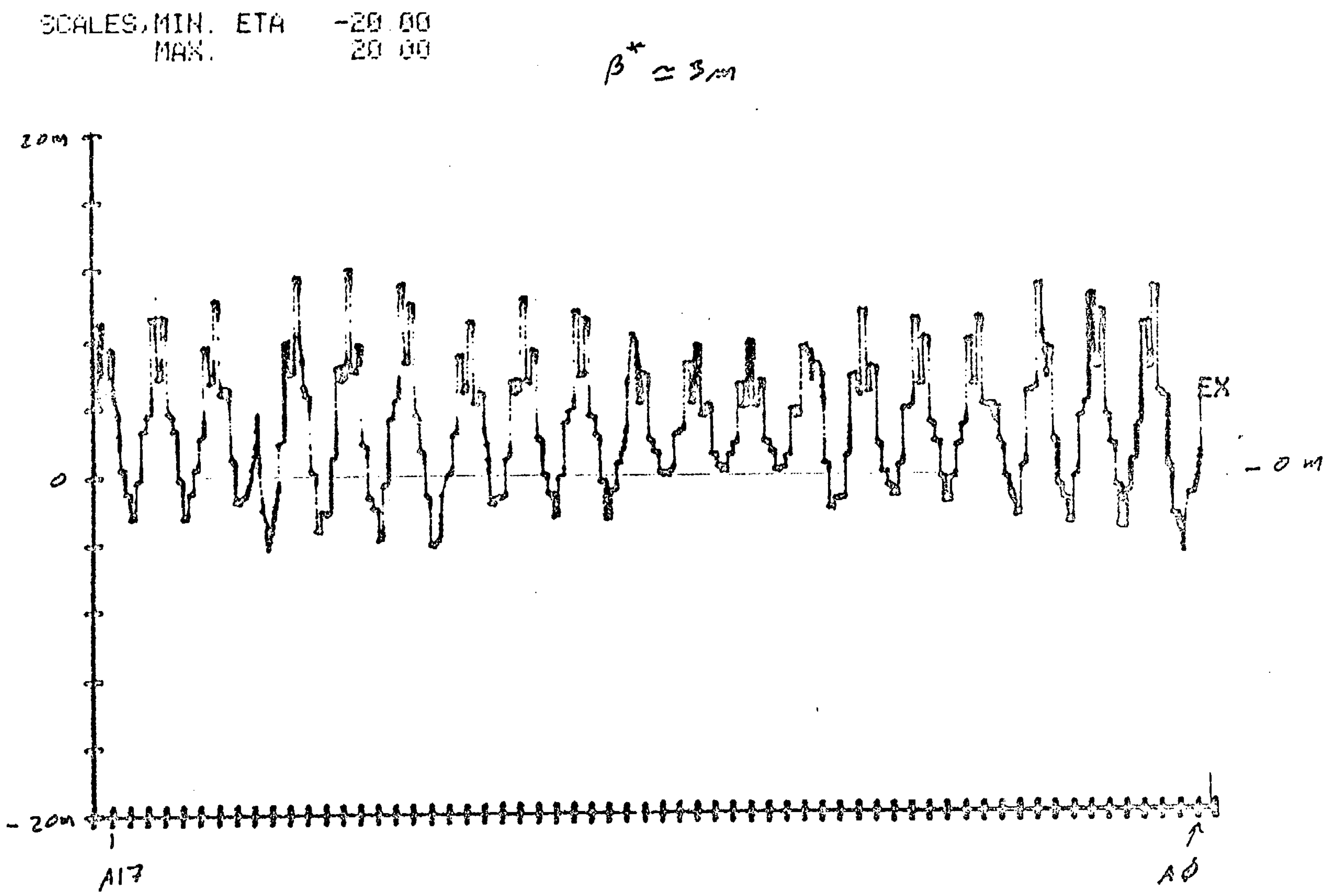

SCALES, MIN. ETA -20.00
MAX. 20.00
$\beta^* \simeq 3m$
20m
0
-20m
A17
A0
EX
- 0m

Figure 5

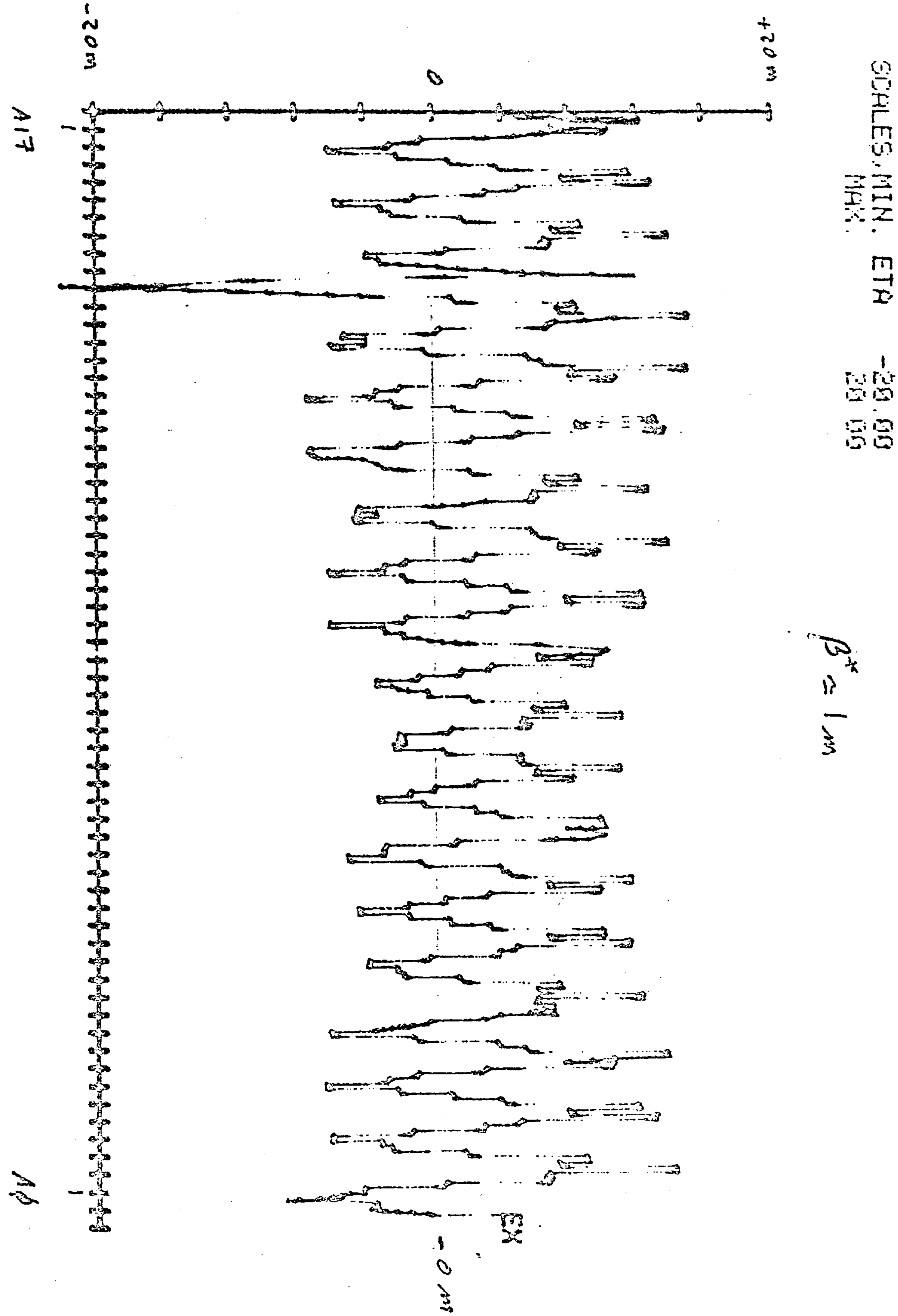
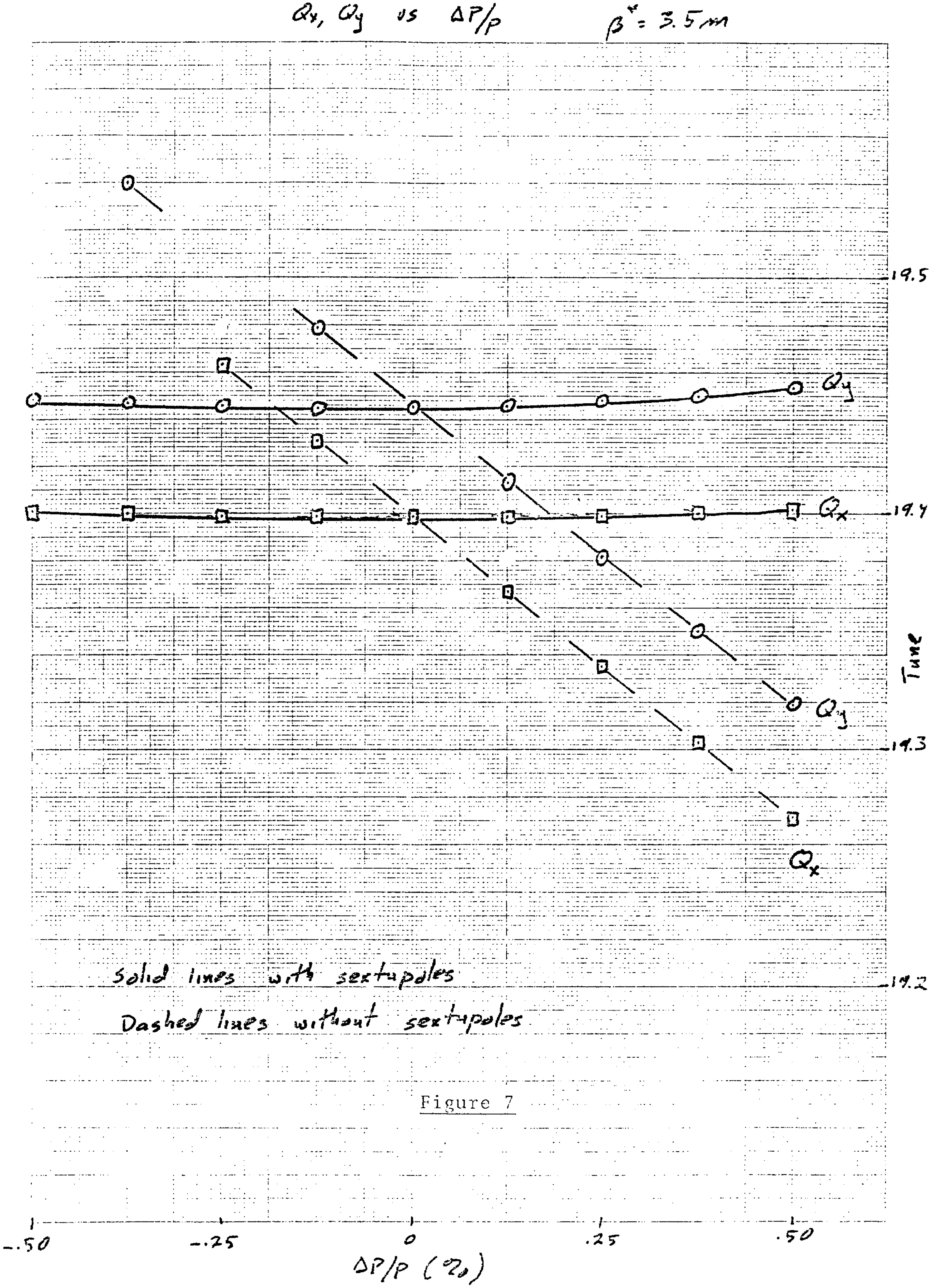


Figure 6



Qx, Qy vs ΔP/p
β* = 3.5 m
Qy
Qx
Qy
Qx
19.5
19.4
19.3
19.2
Tune
Solid lines with sextupoles
Dashed lines without sextupoles
-.50
-.25
0
.25
.50
ΔP/P (%)

Figure 7

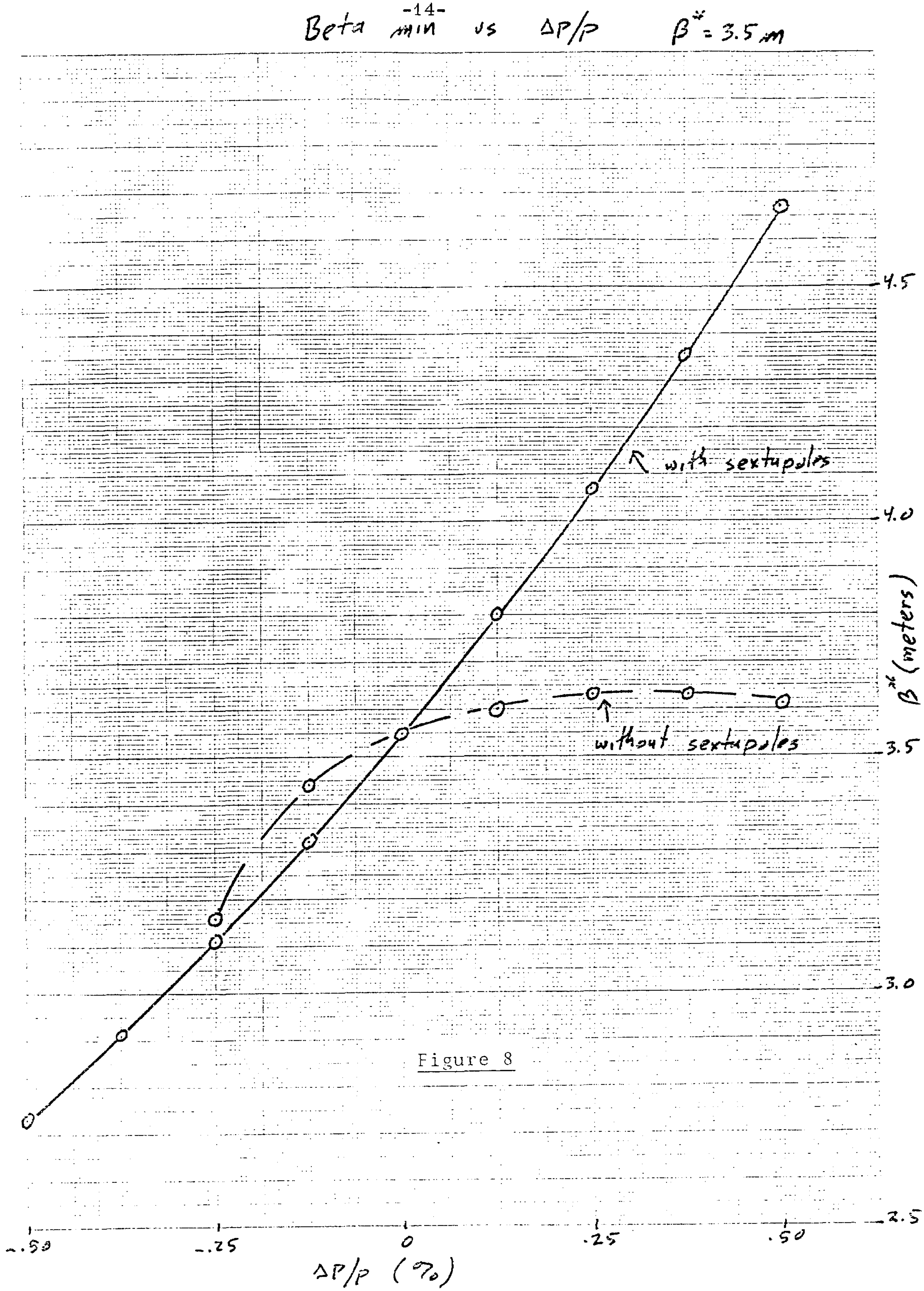
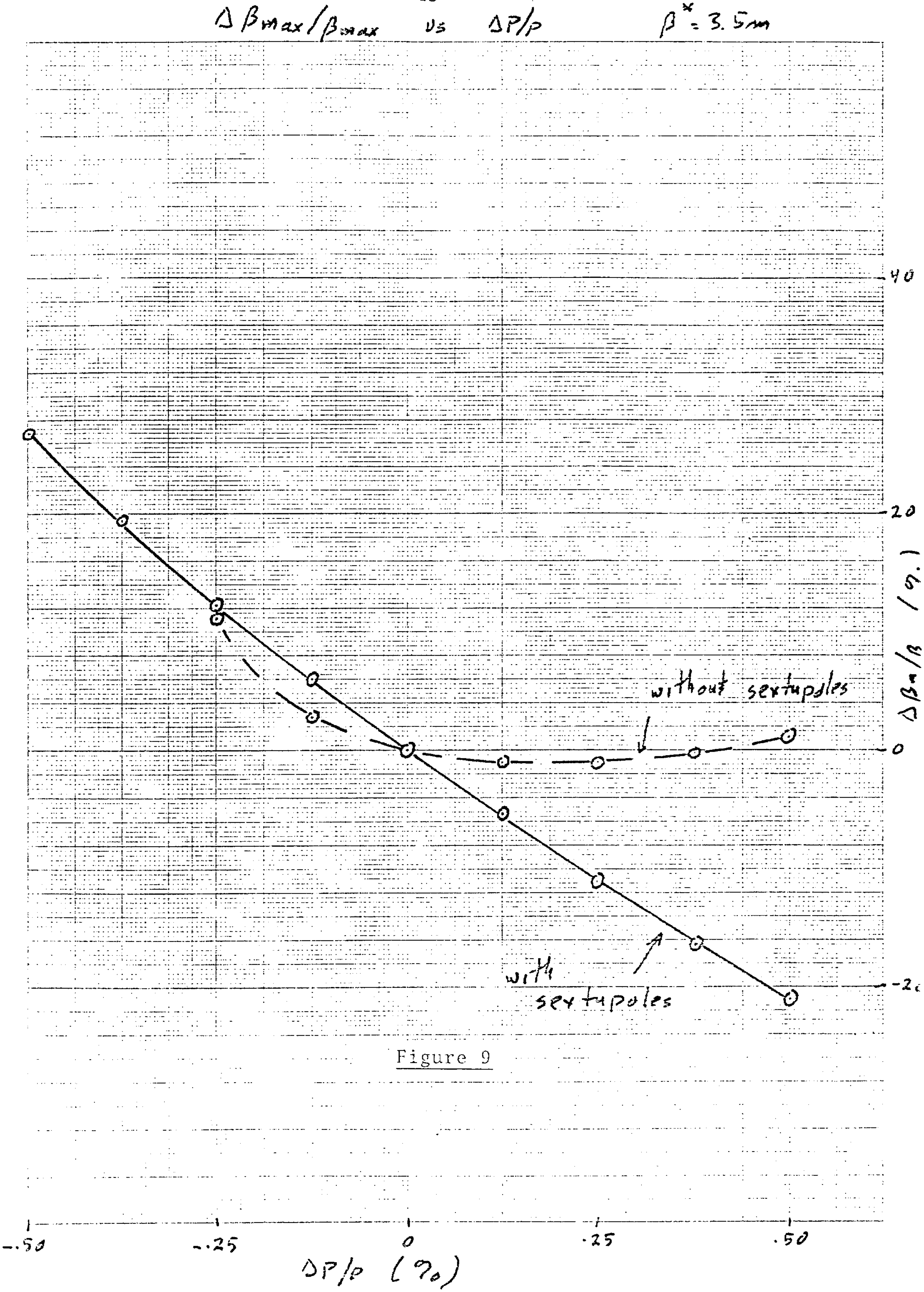

Beta min vs ΔP/P β* = 3.5 m
with sextupoles
without sextupoles
4.5
4.0
3.5
3.0
2.5
β* (meters)
-.50
-.25
0
.25
.50
ΔP/P (%)

Figure 8



Δβmax/βmax vs ΔP/P β* = 3.5m
40
20
0
-20
Δβm/β (%)
without sextupoles
with sextupoles
-.50
-.25
0
.25
.50
ΔP/P (%)

Figure 9

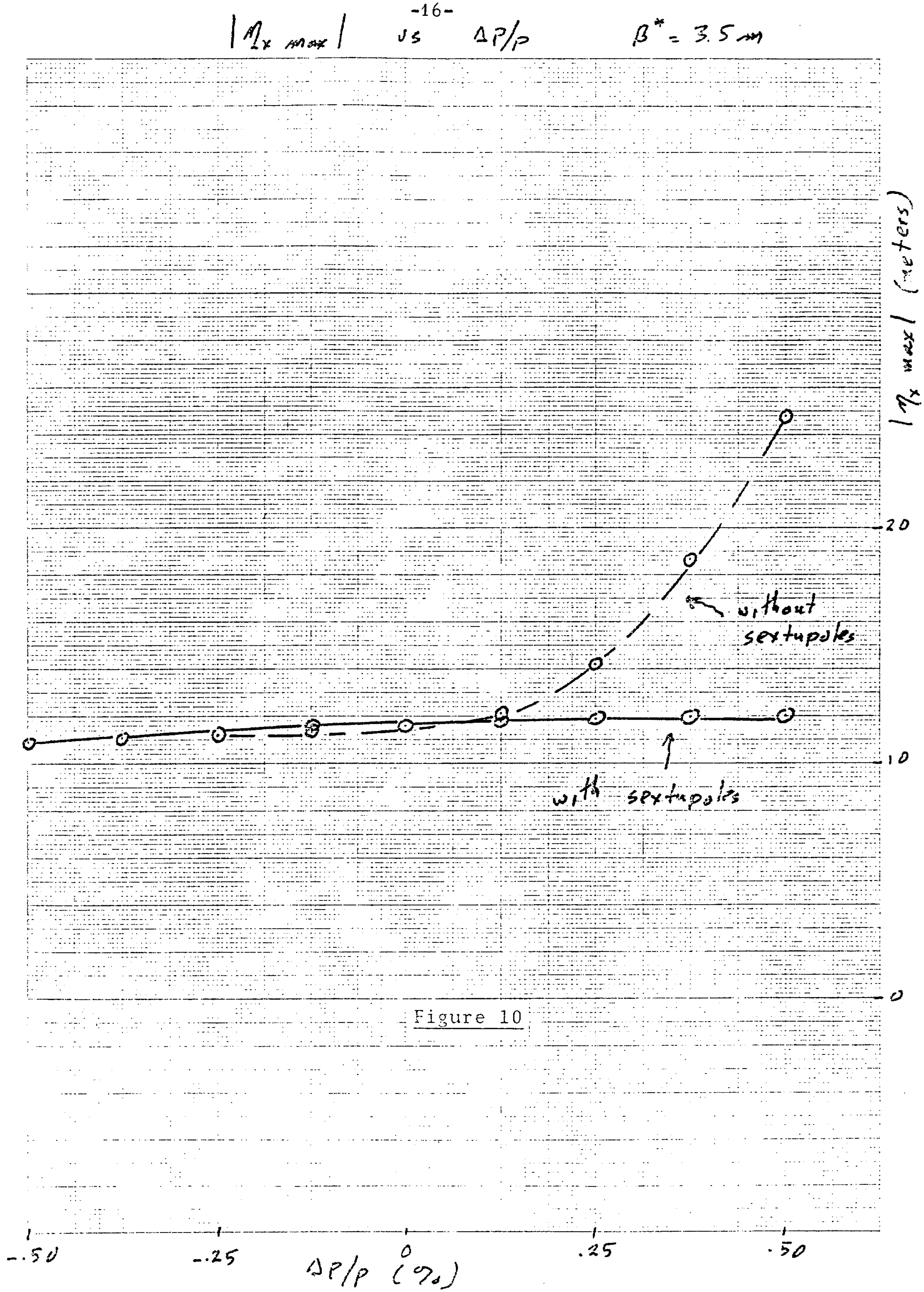
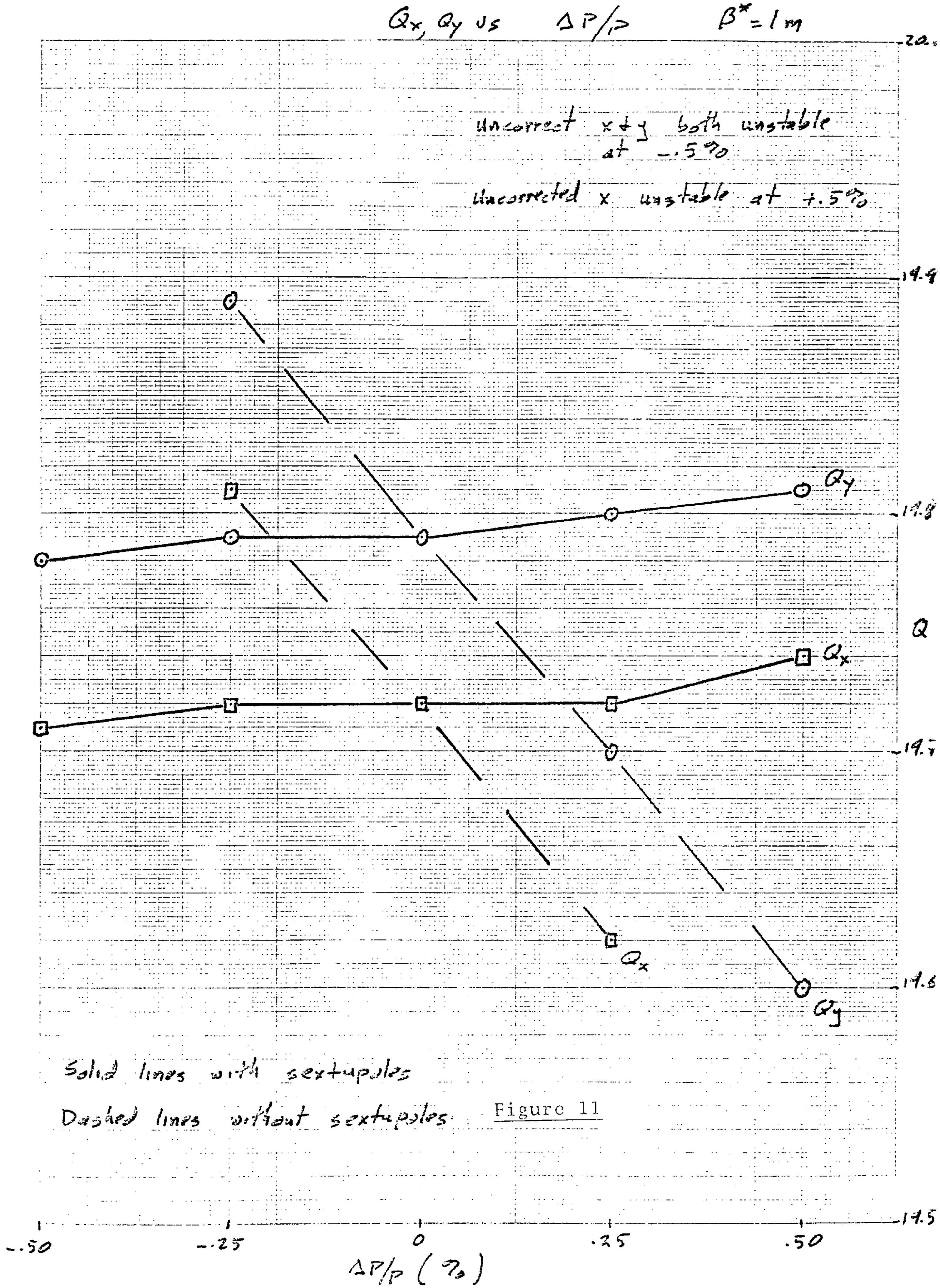

$|\eta_{x\,max}|$ vs $\Delta P/P$ $\beta^* = 3.5$ m
$|\eta_{x\,max}|$ (meters)
20
10
0
without sextupoles
with sextupoles
-.50
-.25
0
.25
.50
$\Delta P/P$ (%)

Figure 10



Solid lines with sextupoles

Dashed lines without sextupoles. Figure 11

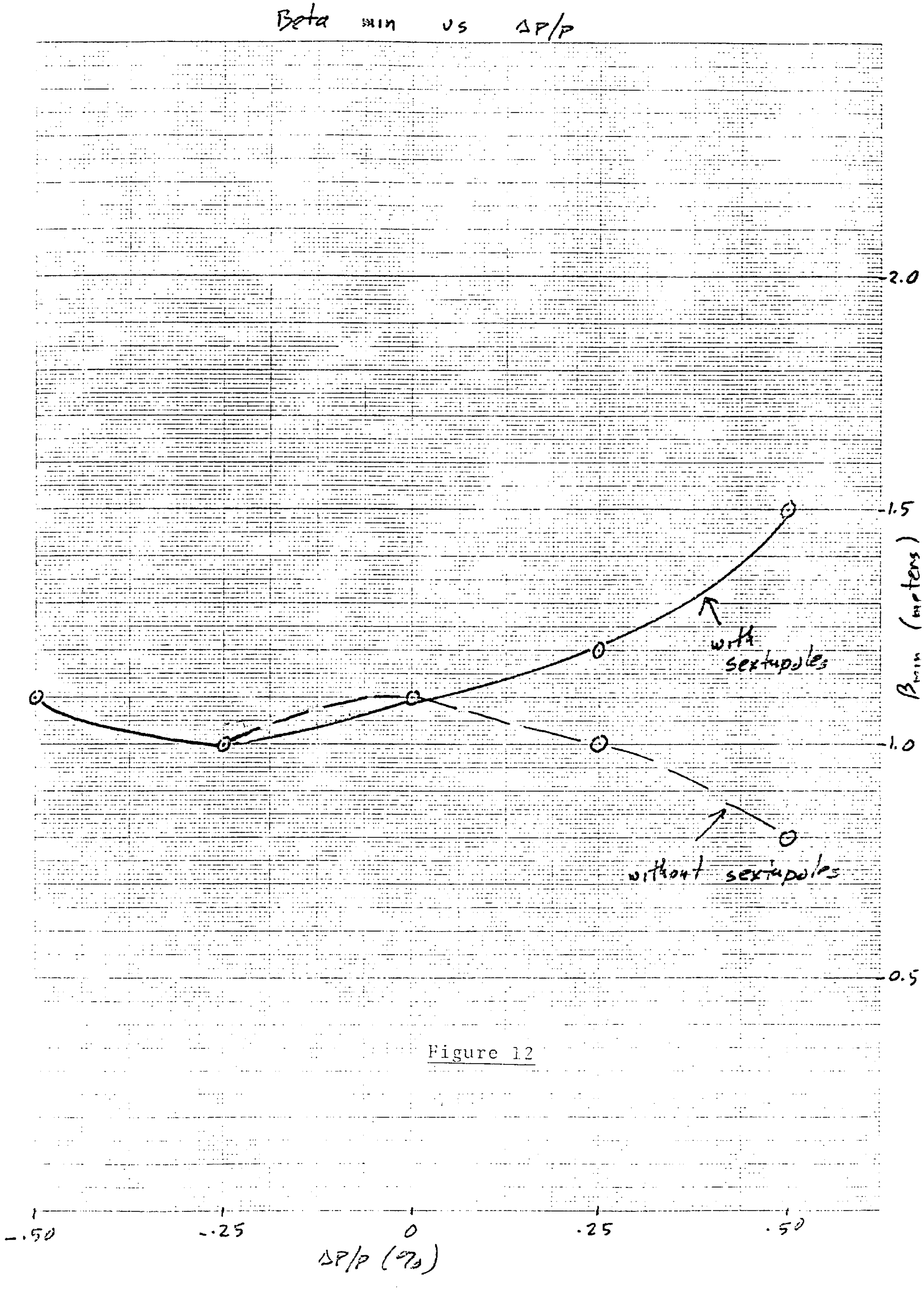

Beta min vs ΔP/p
2.0
1.5
1.0
0.5
β_{min} (meters)
with sextupoles
without sextupoles
-.50
-.25
0
.25
.50
ΔP/p (%)

Figure 12

$\Delta\beta_{max}/\beta_{max}$ vs $\Delta P/P$ $\beta^* = 1m$

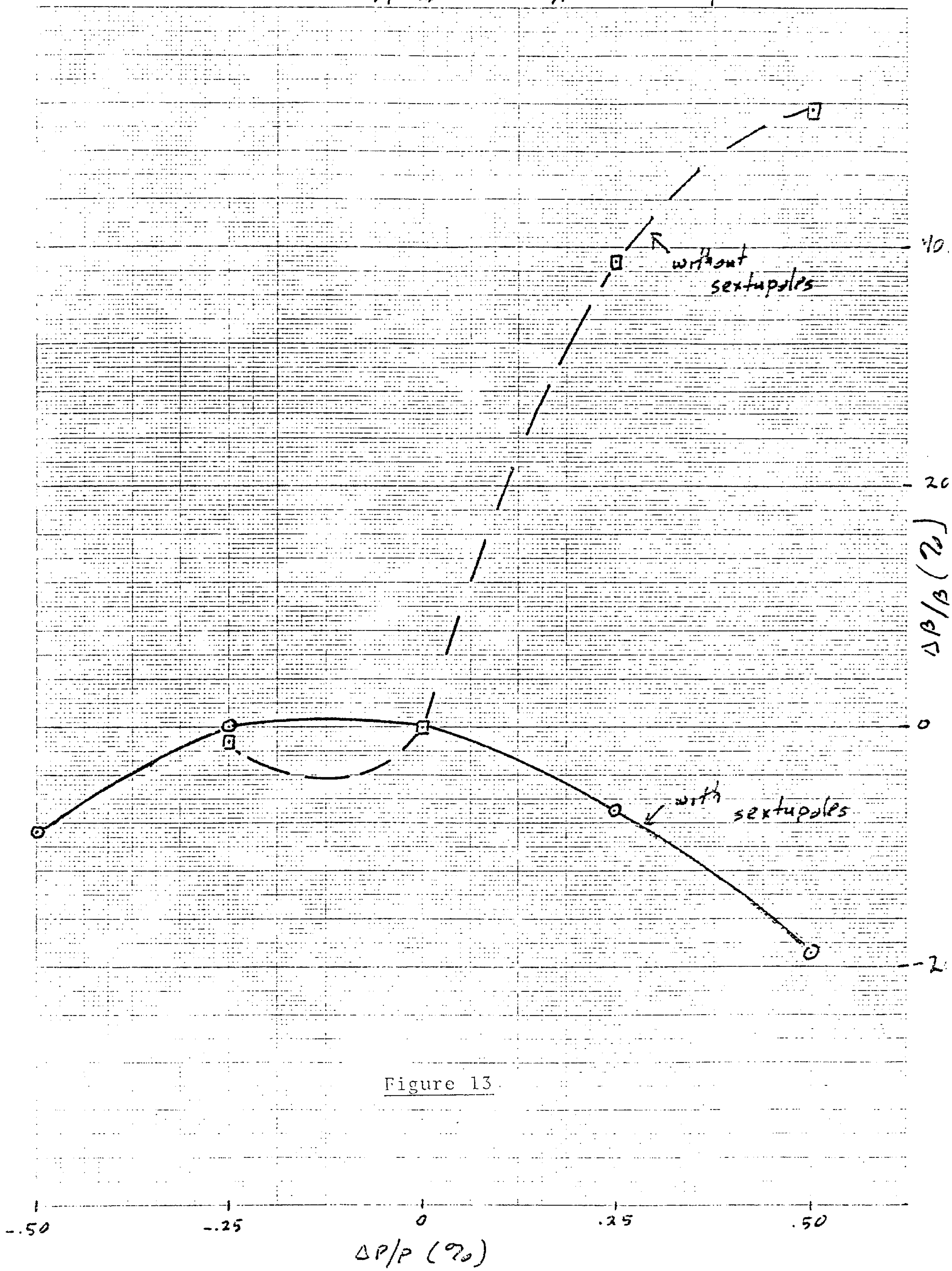
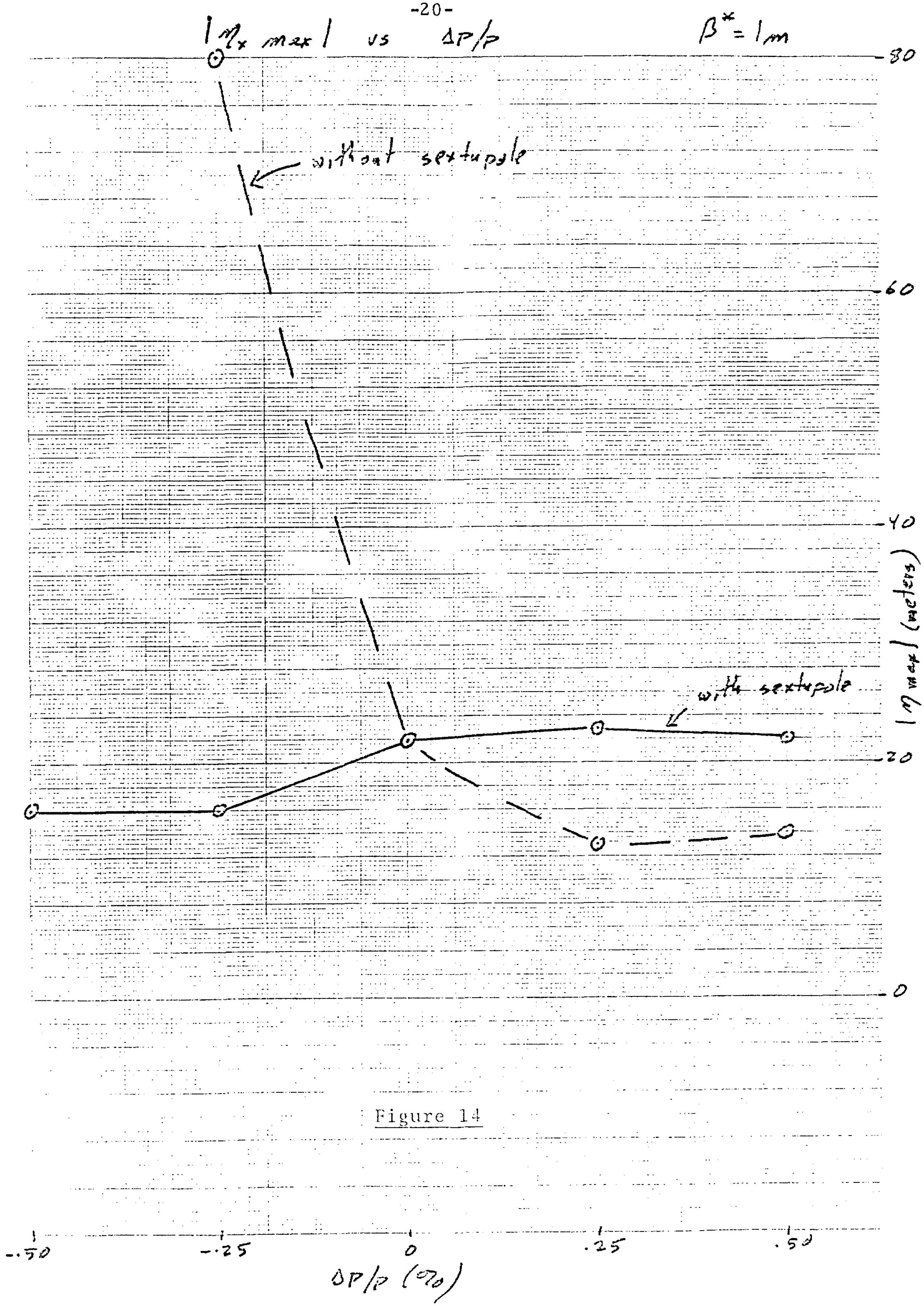


Figure 13



|η_x max| vs ΔP/P
β* = 1m
80
60
40
20
0
without sextupole
with sextupole
|η max| (meters)
-.50
-.25
0
.25
.50
ΔP/P (%)

Figure 14